Figures

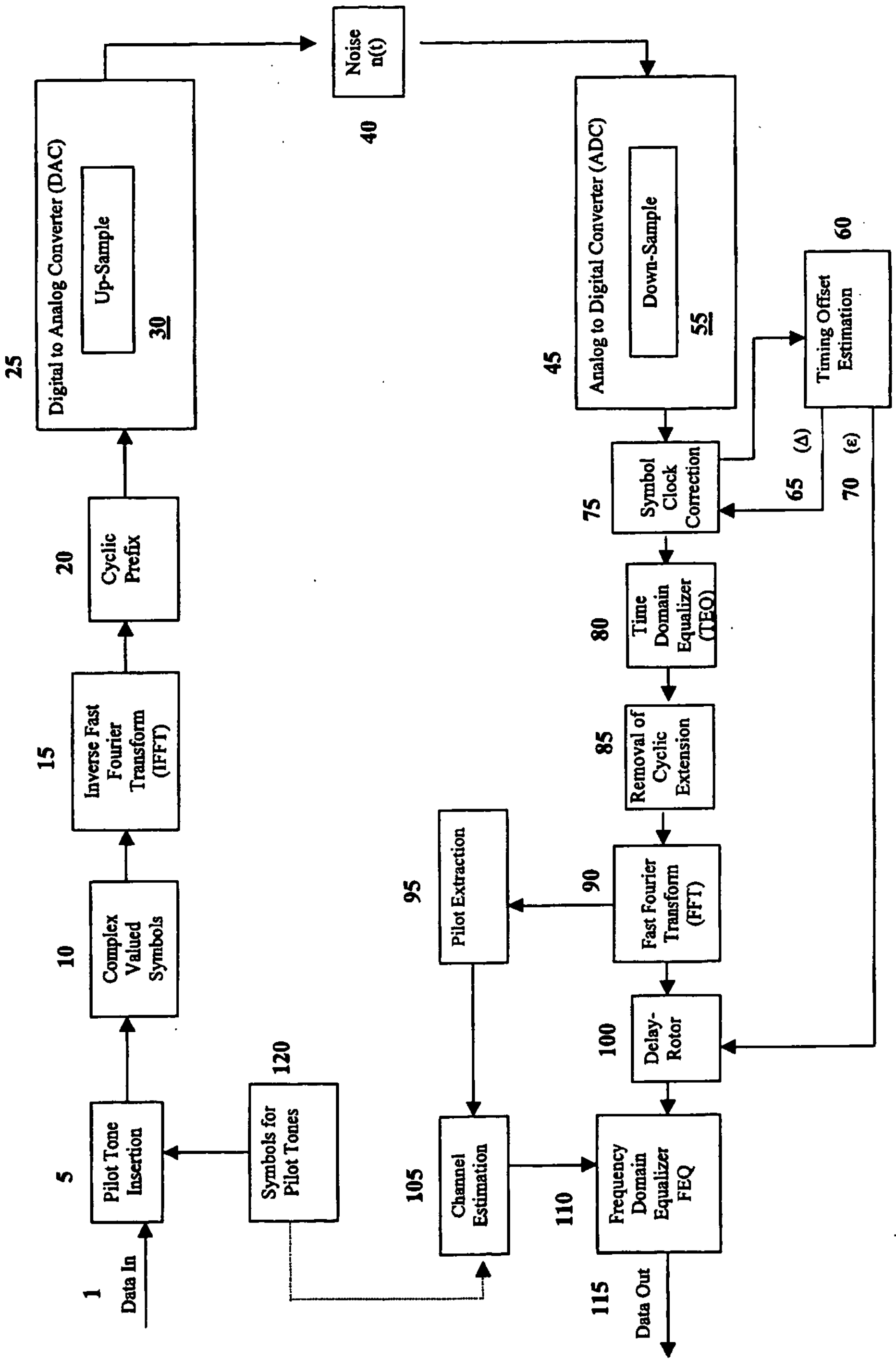

1
Data In
5
Pilot Tone Insertion
120
Symbols for Pilot Tones
10
Complex Valued Symbols
15
Inverse Fast Fourier Transform (IFFT)
20
Cyclic Prefix
25
Digital to Analog Converter (DAC)
Up-Sample
30
Noise n(t)
40
45
Analog to Digital Converter (ADC)
Down-Sample
55
60
Timing Offset Estimation
65
(Δ)
70
(ε)
75
Symbol Clock Correction
80
Time Domain Equalizer (TEQ)
85
Removal of Cyclic Extension
90
Fast Fourier Transform (FFT)
95
Pilot Extraction
100
Delay-Rotor
105
Channel Estimation
110
Frequency Domain Equalizer FEQ
115
Data Out

FIG. 1

FIG. 2

$$x_n = \sqrt{N} \sum_{k=0}^{N-1} X_k e^{j\frac{2\pi kn}{N}}, n = 0,\ldots,N-1$$ 2-1

where subscript n and k denote time index and sub-carrier index, respectively.

$\underline{X}^m$ is generated such

$$\begin{cases} X^m 0 = X^m N = 0 \\ X^m k = a^m k, k < N \\ X^m N+k = (a^m N-k)^* \end{cases}$$ 2-2

$$x^m -k = x^m N-k$$ 2-3

If the Channel Impulse Response (CIR) is denoted by vector $\underline{h} = [h_0,\ldots,h_{N_c-1}]$, then the received signal can be written as 2-4

$$y_n = h_n x_n + n_n$$

where n_n is the noise sample at n-th time instant.

$$Y_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x_n e^{-j\frac{2\pi kn}{N}}, k = 0,\ldots,N-1$$ 2-5

$$Y^m k = H_k X^m k + N^m k, k = 0,\ldots,N-1$$ 2-6

Here, uppercase letters represent FFT of the corresponding time-domain signals.

FIG. 3

$$R(\hat{D})=\sum_{n=0}^{LP-1} r(n+\hat{D})r(n+N+\hat{D}); \quad \hat{D}=0,1,\cdots,\hat{D}_{\max}$$ 3-1

where $r(n)$ is the received signal sample at n-th instant, $\hat{D}_{\max}$ is the maximum possible delay. From the correlation function values for various delays, $\hat{D}$ is selected where the function has the maximum value.

3-2

$$\{i, \quad i+N/L \quad \cdots \quad i+N-N/L\}, i=0,1,\ldots,N/L-1.$$

$$R^m{}_k = H_k + \frac{V^m{}_k}{|X^m{}_k|}, k=0,\ldots,N-1$$

3-3

where $R^m{}_k = \frac{Y_k^m}{X_k^m}$ and $V^m{}_k = \frac{N_k^m}{e^{j\angle X_k^m}}$

Where vectors $\underline{\hat{h}} = [h_0 \quad h_1 \quad \cdots \quad h_{L-1}]$ and

$\underline{R}_{pl} = [R_i \quad R_{i+N/L} \quad \cdots \quad R_{i+N-N/L}]$, and the matrix Q_{pl} is defined as:

$$Q_{pl} = \frac{1}{\sqrt{N}}\begin{bmatrix} 1 & W_N^i & \cdots & W_N^{i(L-1)} \\ 1 & W_N^{(i+N/L)} & \cdots & W_N^{(i+N/L)(L-1)} \\ \cdots & \cdots & \cdots & \cdots \\ 1 & W_N^{(i+N-N/L)} & \cdots & W_N^{(i+N-N/L)(L-1)} \end{bmatrix}$$ 3-4

where $W_N = e^{-j\frac{2\pi}{N}}$.

FIG. 4

$$MSE_{normalized} = \frac{\mathrm{E}\|\hat{h} - h\|^2}{\mathrm{E}\|h\|^2} \qquad 4\text{-}1$$

where $\underline{h}$ is the actual channel and $\underline{\hat{h}}$ is the MMSE estimation

4-2

$$C_k = \frac{1}{H_k} \quad , k = 0,1, \ldots, N\text{-}1$$

$$C_k = \frac{H_k^*}{|H_k|^2 + \sigma_n^2/\sigma_a^2} \qquad 4\text{-}3$$

FIG. 5

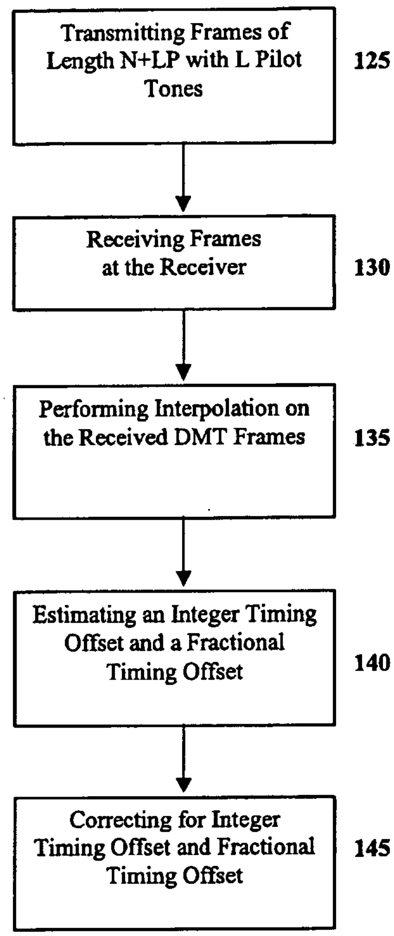

Transmitting Frames of Length N+LP with L Pilot Tones
125
Receiving Frames at the Receiver
130
Performing Interpolation on the Received DMT Frames
135
Estimating an Integer Timing Offset and a Fractional Timing Offset
140
Correcting for Integer Timing Offset and Fractional Timing Offset
145

FIG. 6

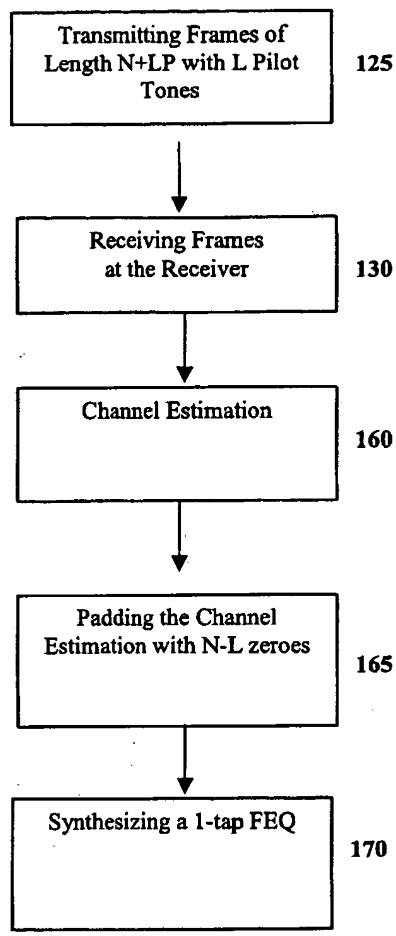

Transmitting Frames of Length N+LP with L Pilot Tones
125
Receiving Frames at the Receiver
130
Channel Estimation
160
Padding the Channel Estimation with N-L zeroes
165
Synthesizing a 1-tap FEQ
170

FIG. 7

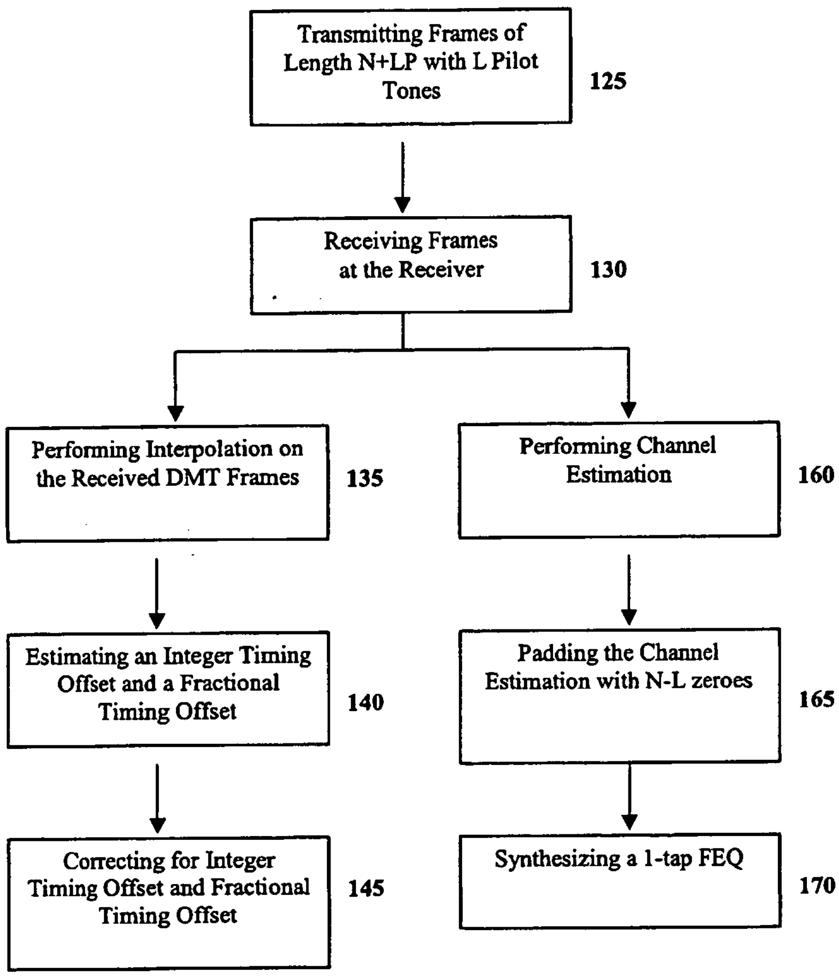

Transmitting Frames of Length N+LP with L Pilot Tones
125
Receiving Frames at the Receiver
130
Performing Interpolation on the Received DMT Frames
135
Estimating an Integer Timing Offset and a Fractional Timing Offset
140
Correcting for Integer Timing Offset and Fractional Timing Offset
145
Performing Channel Estimation
160
Padding the Channel Estimation with N-L zeroes
165
Synthesizing a 1-tap FEQ
170

FIG. 8

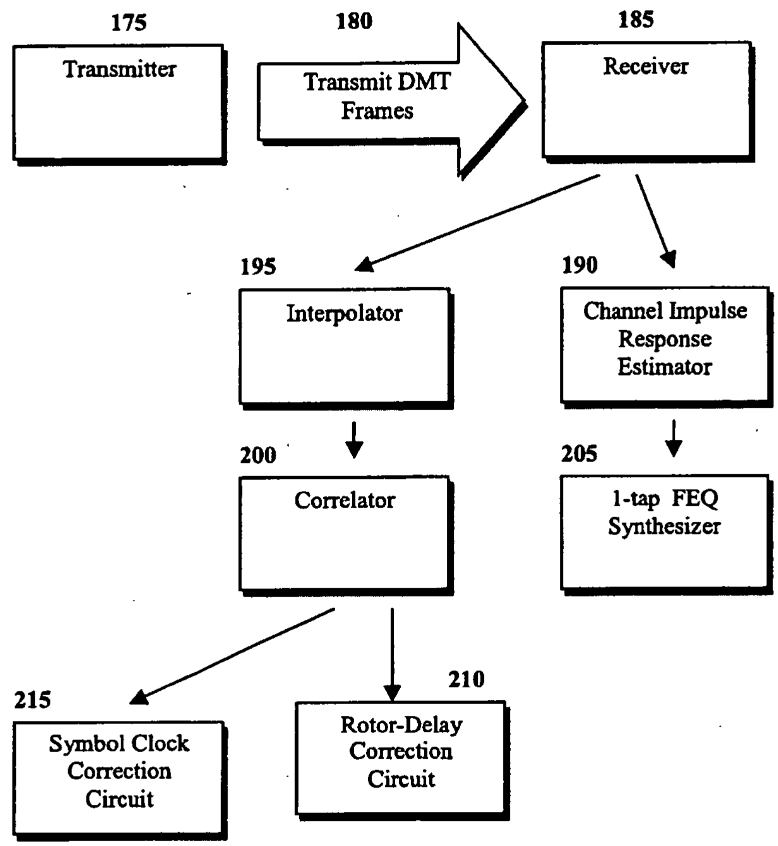

175
Transmitter
180
Transmit DMT Frames
185
Receiver
195
Interpolator
190
Channel Impulse Response Estimator
200
Correlator
205
1-tap FEQ Synthesizer
215
Symbol Clock Correction Circuit
210
Rotor-Delay Correction Circuit

FIG. 9

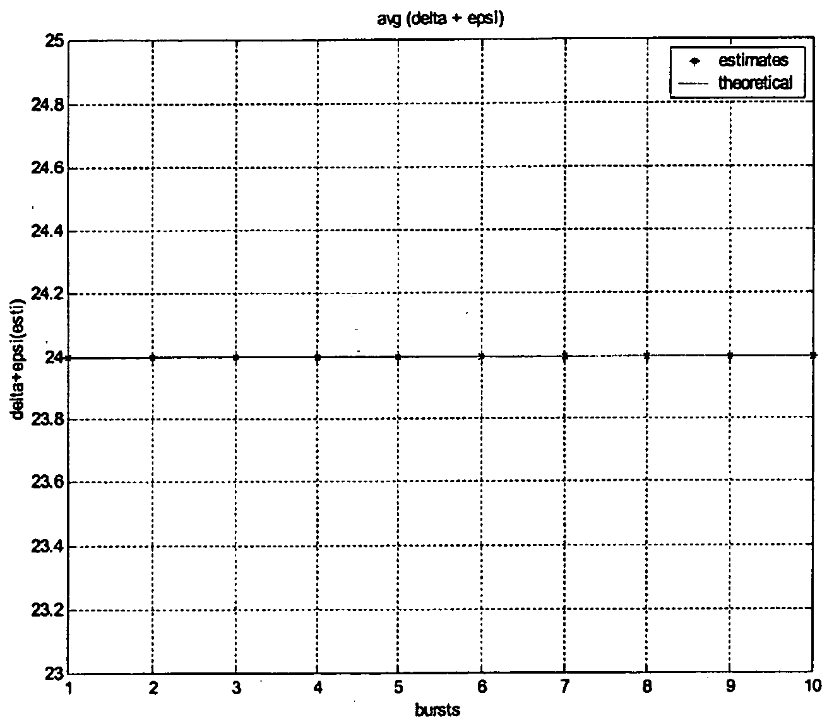

avg (delta + epsi)
estimates
theoretical
delta+epsi(esti)
25
24.8
24.6
24.4
24.2
24
23.8
23.6
23.4
23.2
23
1
2
3
4
5
6
7
8
9
10
bursts

FIG. 10

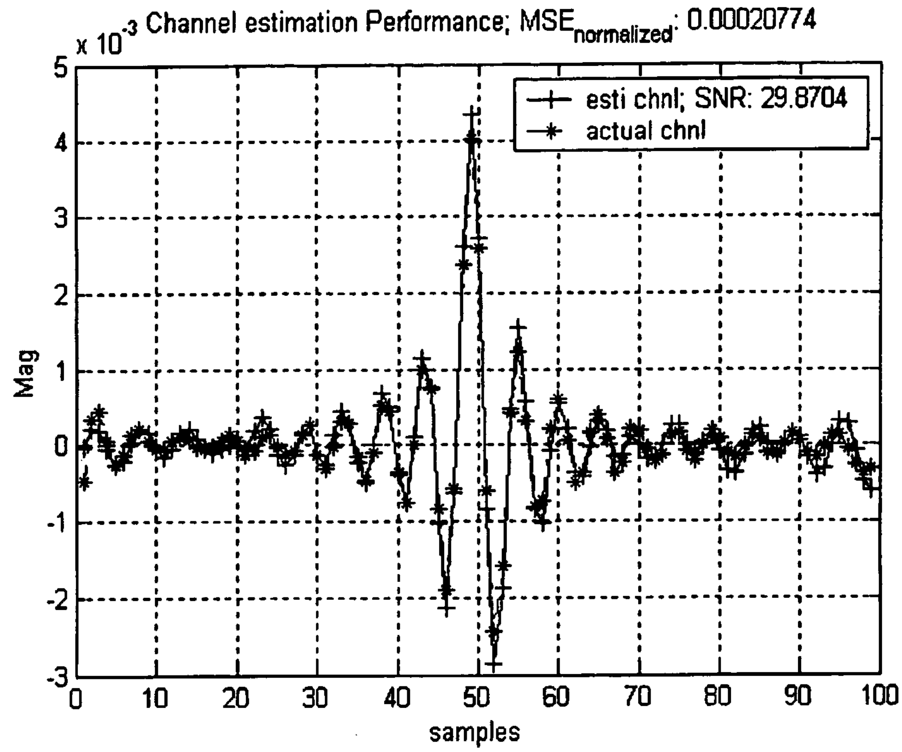
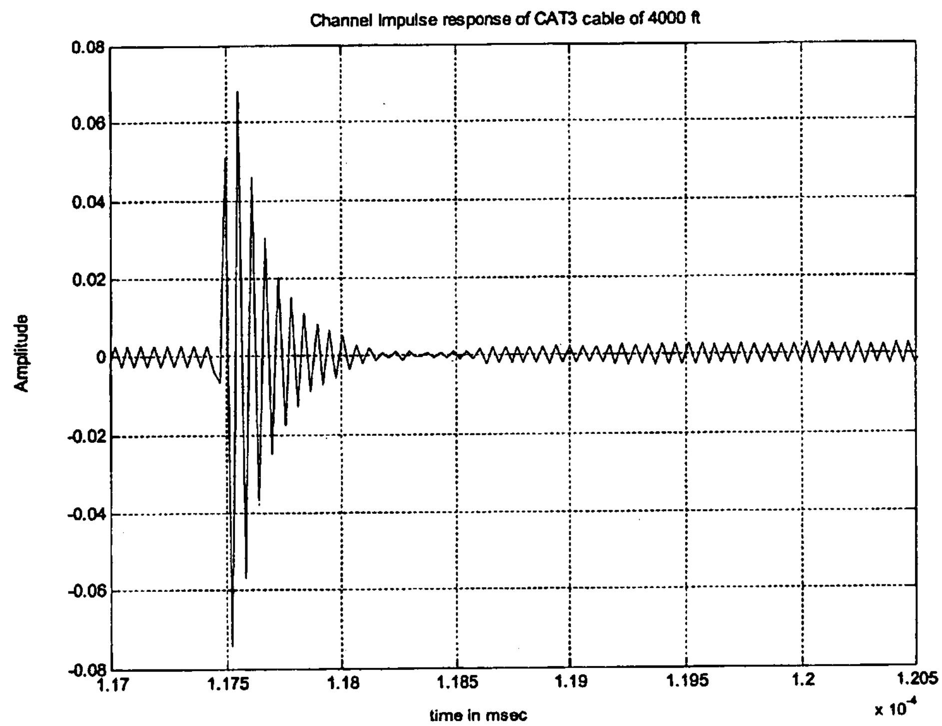

x 10^-3 Channel estimation Performance; MSE normalized: 0.00020774
esti chnl; SNR: 29.8704
actual chnl
Mag
samples
5
4
3
2
1
0
-1
-2
-3
0
10
20
30
40
50
60
70
80
90
100

FIG. 11


Channel Impulse response of CAT3 cable of 4000 ft
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
Amplitude
1.17
1.175
1.18
1.185
1.19
1.195
1.2
1.205
x 10^-4
time in msec